(Some) uncertainties in the near-infrared radiation budget

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Particular thanks to Jon Elsey (Univ of Reading), Igor Ptashnik (IAO, Tomsk) and Tom Gardiner and Marc Coleman (NPL)

Earth Radiation Budget Workshop, ECMWF October 2016

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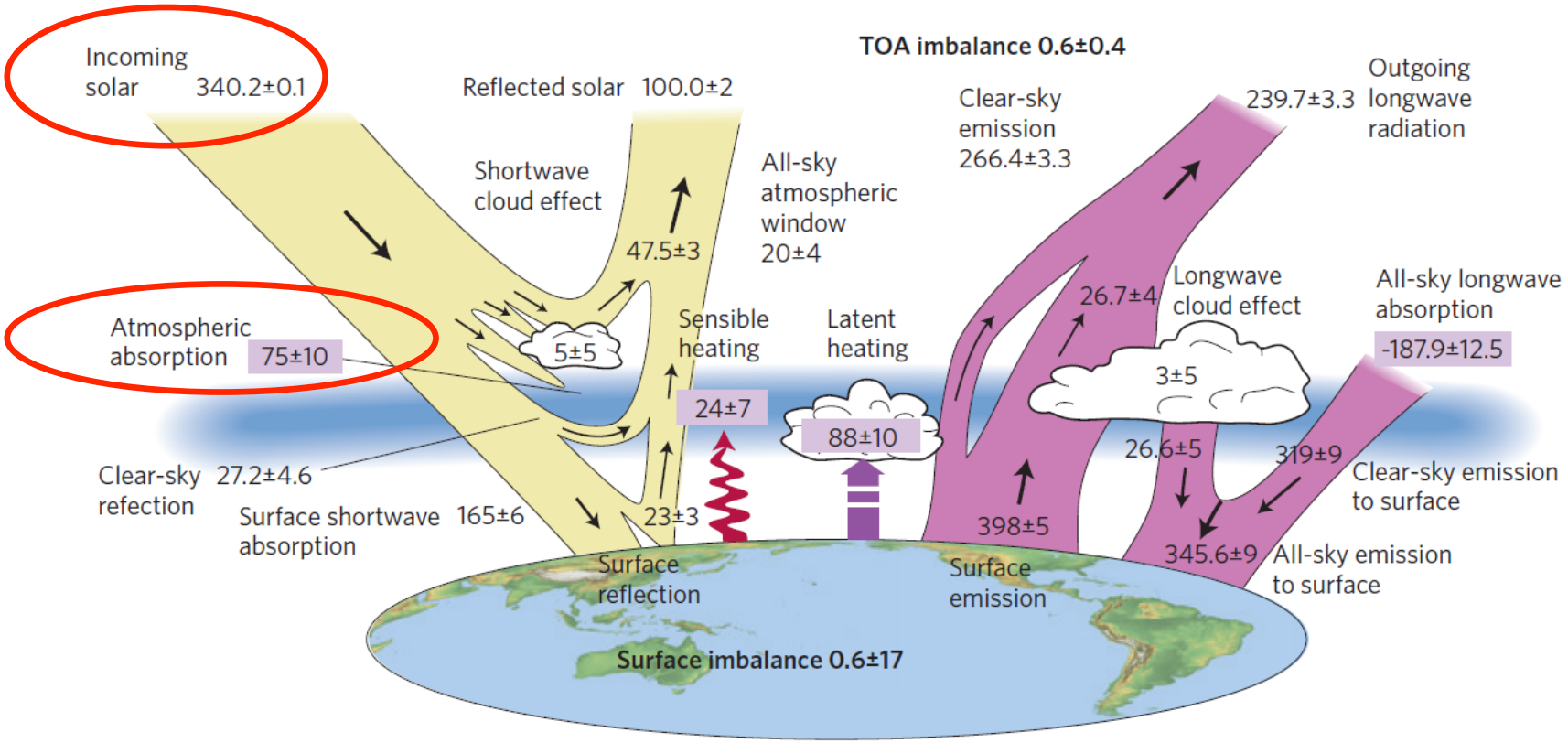
Modern (global and annual averaged) Earth energy budget



Stephens et al. (2012), Nature Geoscience 10.1038/NGEO1580

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A surprising uncertainty!

- The wavelength-integrated total solar irradiance is believed to be known with an uncertainty of less than 0.5% (e.g. Kopp and Lean 2011)
- But how well do we know the spectrally-resolved irradiance?

The near-IR Extraterrestrial Solar Spectrum (NIR ESS)

- ESS are readily available, even if not at the highest spectral resolution (so that many solar lines are not resolved). OK?

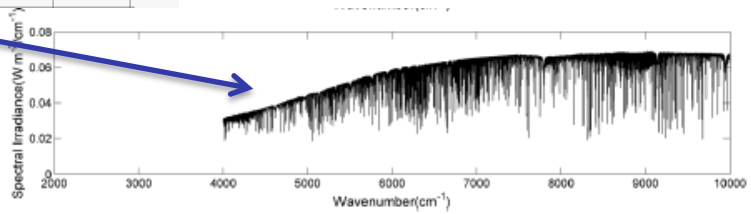

Figure 9. (top) CAVIAR ESS at one astronomical unit (1 AU) from 2000–10,000 cm^{-1} (1–5 μm). (bottom) The merged CAVIAR ESS from 4000–10,000 cm^{-1} (1–2.5 μm). This ESS is a merger of the CAVIAR ESS derived using observations of 18 September 2008 with the ACE-FTS ESS, Kurucz-observed ESS, and Kurucz-modeled ESS.

Menang et al 2013, JGR 10.1002/jgrd.50425

http://lasp.colorado.edu/lisird/sorce/sorce_ssi/

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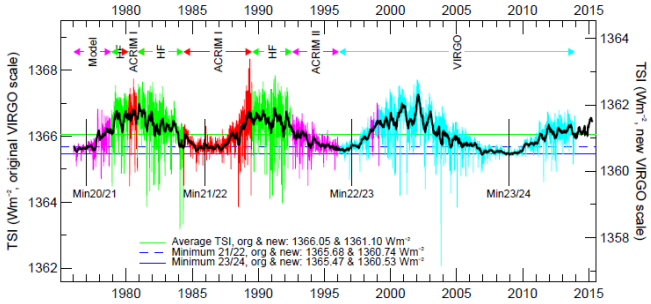
SOLSPEC

- Grating spectrometer, covering (about) 0.17 to 3.1 µm at about 0.5 nm resolution (around 20 cm^{-1})
- First flew on Spacelab I in 1983
- Refurbished and flew on three "ATLAS" Space Shuttle missions (1992-1994). **ATLAS3** became a widely-used reference spectrum



- Also flew on European EUREKA mission in 1994 (but called SOSP)
- Then installed on **International Space Station in 2008**

updated electronics and optical components. Extensive lamp-calibration equipment was incorporated, and synchronous IR signal detection was implemented by the Belgian Institute for Space Aeronomy (BIRA-IASB). After alignment of the optics and vacuum and mechanical tests, the new SOLSPEC was calibrated at the Physikalisch-Technische Bundesanstalt (PTB; Braunschweig, Germany) using a blackbody as reference (Thuillier *et al.*, 2009).

Solar Phys
DOI 10.1007/s11207-013-0461-y

The Solar Irradiance Spectrum at Solar Activity Minimum Between Solar Cycles 23 and 24

G. Thuillier · D. Bolsée · G. Schmidtke · T. Foujols · B. Nikutowski · A.I. Shapiro · R. Brunner · M. Weber · C. Erhardt · M. Hersé · D. Gillotay · W. Peetermans · W. Decuyper · N. Pereira · M. Haberreiter · H. Mandel · W. Schmutz

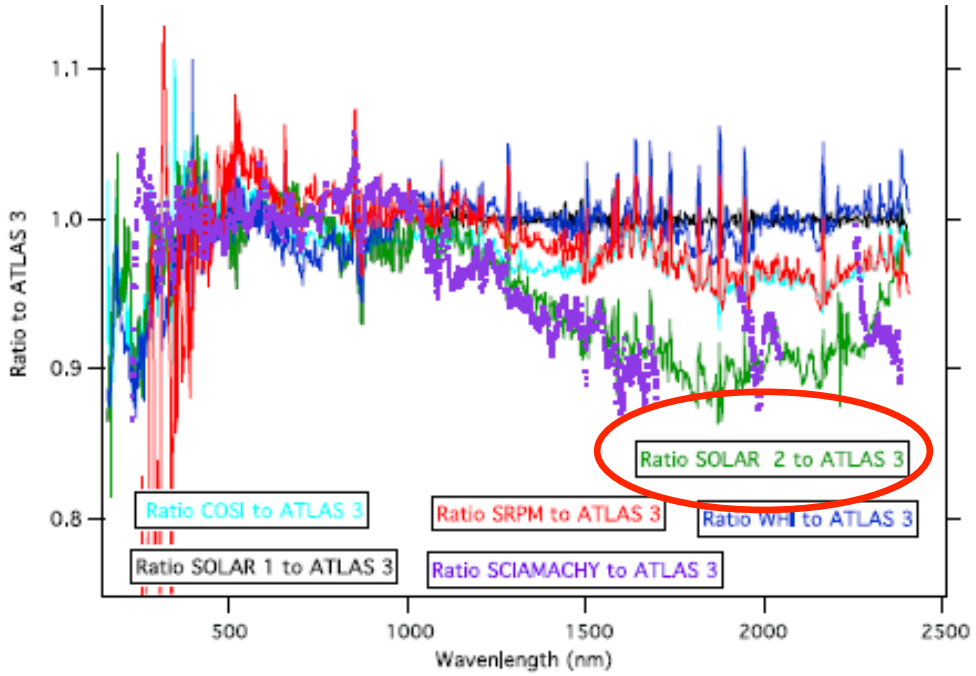


Figure 10 Ratio to ATLAS 3 of the SOLAR 1 and 2 composites, COSI, SRPM, SCIAMACHY, and WHI from 150 to 2400 nm. The main differences are in the IR. We recall that the SOLAR 1 and WHI spectra (using SORCE/SIM) were adjusted to match ATLAS 3 in the IR.

Thuillier et al. (2014) had shown that "new" (2008) NIR ESS measurements were 7% lower than ATLAS-3 at > 1.5 μm, and that the lower values were consistent with e.g. Sciamachy

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Solar Phys
DOI 10.1007/s11207-014-0474-1

Accurate Determination of the TOA Solar Spectral NIR Irradiance Using a Primary Standard Source and the Bouguer–Langley Technique

D. Bolsée · N. Pereira · W. Decuyper · D. Gillotay · H. Yu · P. Sperfeld · S. Pape · E. Cuevas · A. Redondas · Y. Hernandéz · M. Weber

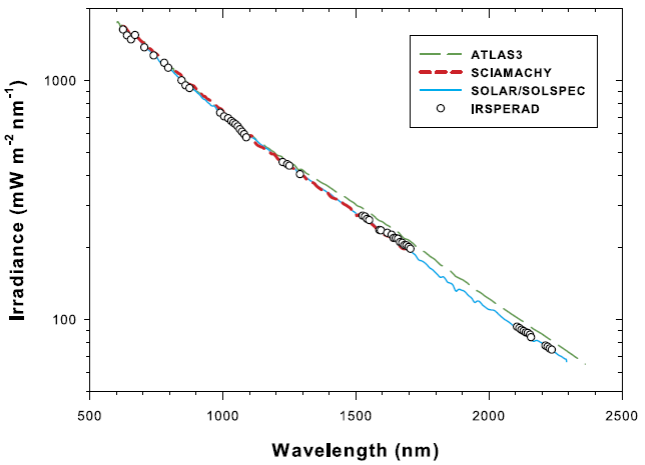
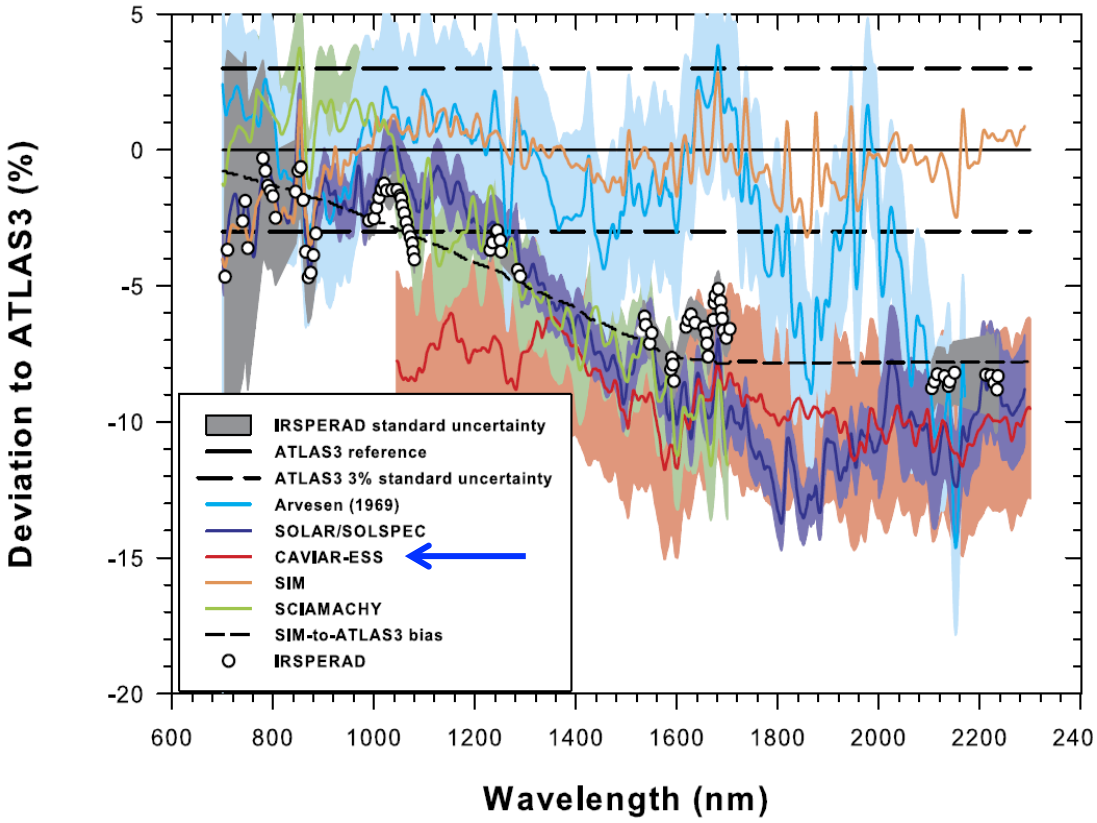


Figure 13 Comparison between different versions of the SOLSPEC instrument (ATLAS3 and SOLAR/SOLSPEC), SCIAMACHY and ground-based measurements performed at Izaña (IRSPERAD). SCIAMACHY, and ATLAS3 are convoluted to 10 nm.



Bolsée et al. (2014) showed ground-based measurements. Theirs and ours (Menang et al. 2013) were also broadly consistent with the lower values derived by SOLAR2. But then ...

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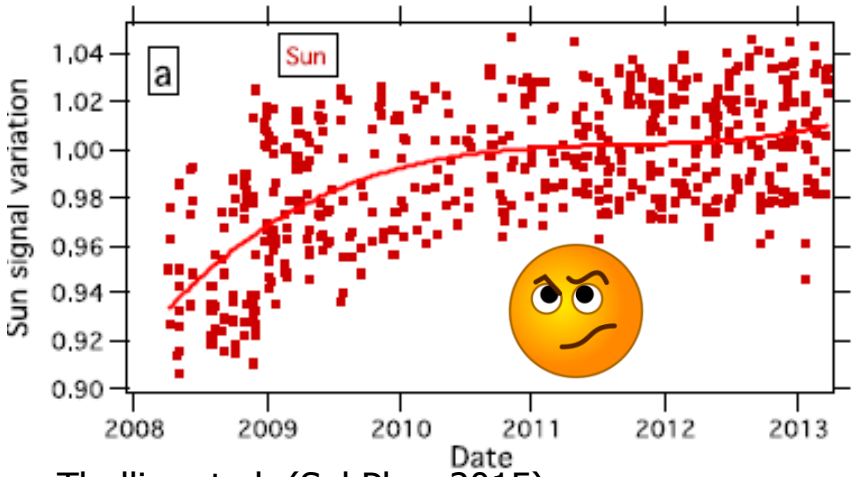
Solar Phys
DOI 10.1007/s11207-015-0704-1

The Infrared Solar Spectrum Measured by the SOLSPEC Spectrometer Onboard the International Space Station

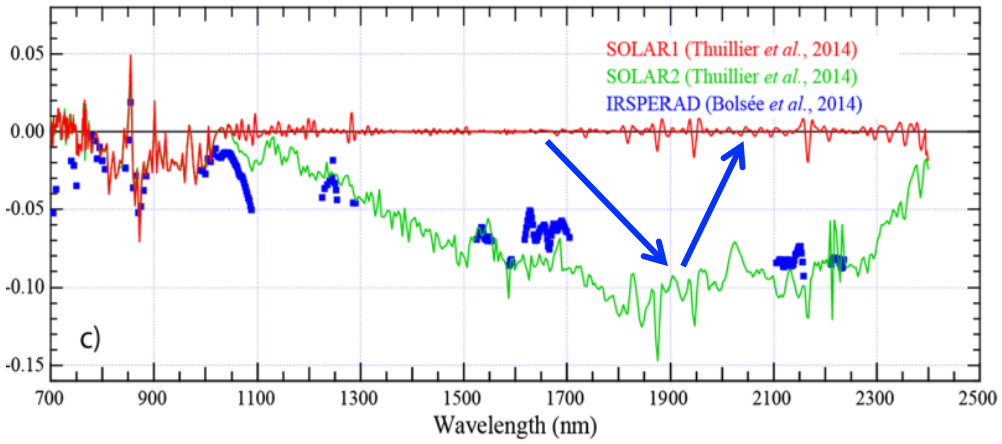
G. Thuillier[1] · J.W. Harder[2] · A. Shapiro[3] · T.N. Woods[2] · J.-M. Perrin[4] · M. Snow[2] · T. Sukhodolov[3] · W. Schmutz[3]

- SOLAR2 was based on ISS "first light" from measurements in April 2008 "to avoid ageing effects"



Thullier et al. (Sol Phys 2015)

- Thullier et al. (2015) "Increase of solar signal (with time) ... (has) no clear explanation ... most likely due to some temperature effect and/or outgassing of the instrument"
- They concluded that the ESS was closer to original ATLAS3 (Solar1) spectrum and evidence supporting the lower SOLAR2 ESS was flawed!



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Not every one agrees with Thuillier et al's conclusion ...

Solar Phys
DOI 10.1007/s11207-015-0707-y

Comment on the Article by Thuillier *et al.* "The Infrared Solar Spectrum Measured by the SOLSPEC Spectrometer onboard the International Space Station"

Invited Review

M. Weber[1]

Solar Phys (2016) 291:2473–2477
DOI 10.1007/s11207-016-0914-1

Comments to the Article by Thuillier *et al.* "The Infrared Solar Spectrum Measured by the SOLSPEC Spectrometer Onboard the International Space Station" on the Interpretation of Ground-based Measurements at the Izaña Site

D. Bolsée[1] · N. Pereira[1] · E. Cuevas[2] · R. García[2] · A. Redondas[2]

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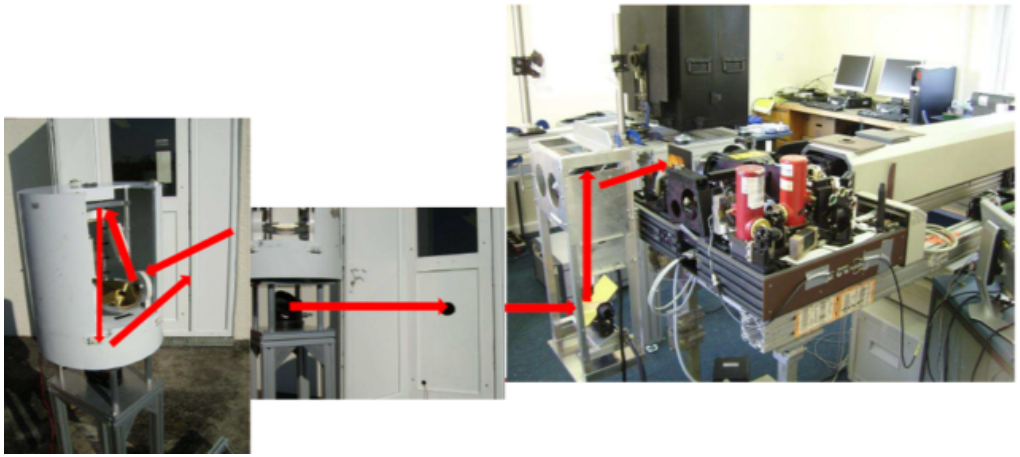
Implications

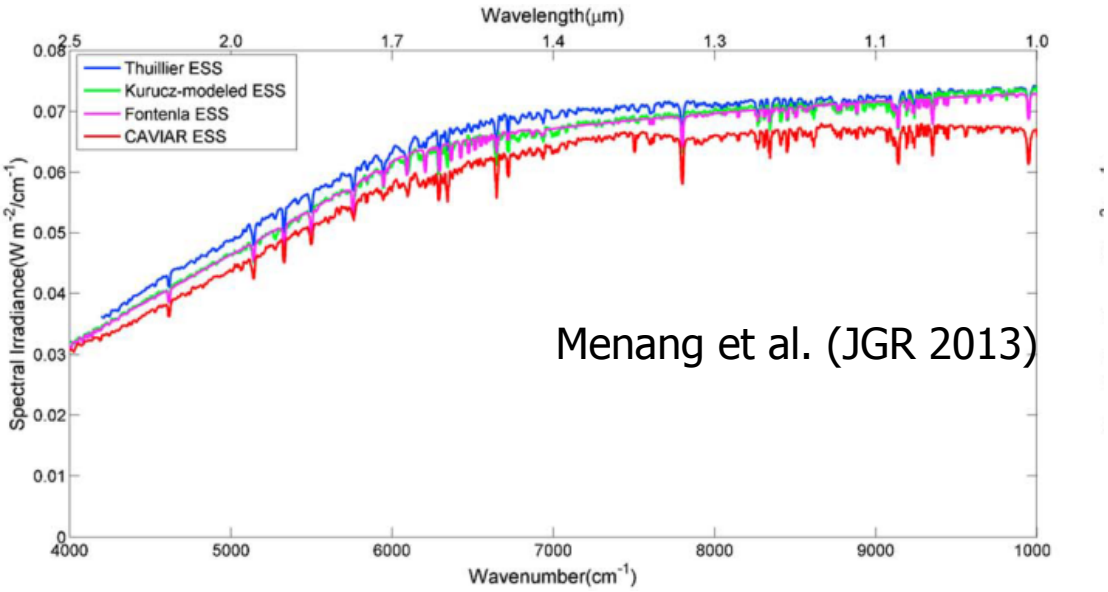
- If ≈30% of the incoming solar radiation is at λ>1 μm, and this is 5-10% uncertain ... and the total solar irradiance is accurate to within 0.5% then ...
- We must be significantly uncertain about the incoming solar radiation in other spectral regions. We can't just "lose" several % of the total solar irradiance

Ground-based sun-pointing FTS measurements

National Physical Laboratory

NPL FTS and sun-tracker





Menang et al. (JGR 2013)

- Calibration traceable to a primary standard cryogenic radiometer
- Field campaign in UK in 2008
- Current work by Jon Elsey (Univ of Reading) builds on previous work by Menang et al. (2013)

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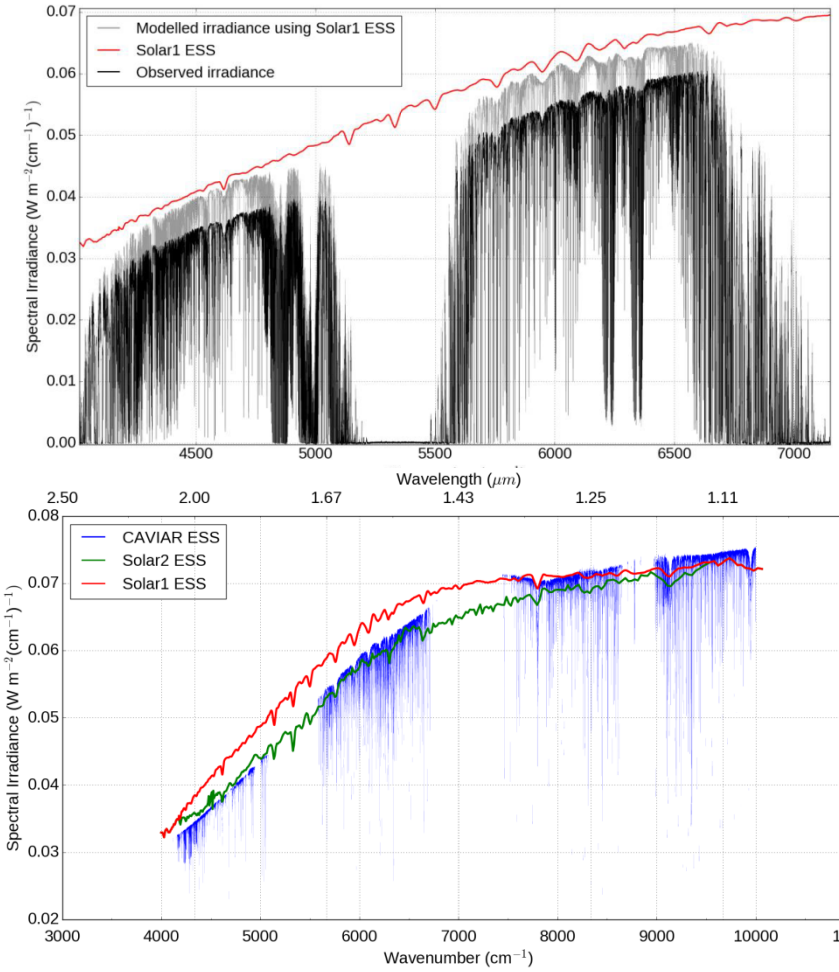
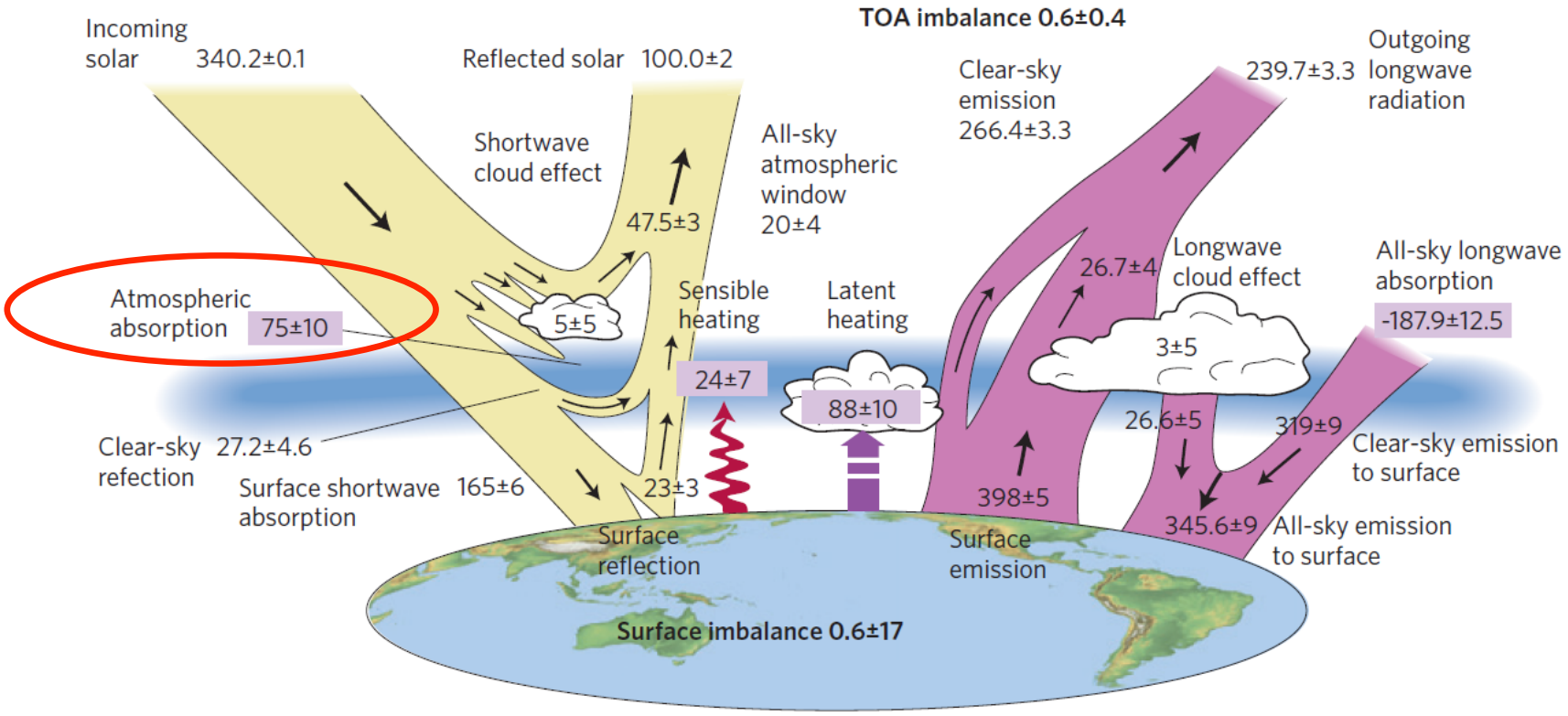
Field campaign results

- Direct modelling of surface spectral irradiance *inconsistent* with observed irradiances using the *higher* SOLSPEC ESS
- Discrepancy is outside known instrumental, spectroscopic or atmospheric state uncertainties
- Updated Langley analysis shows good agreement with the SOLAR2 ESS, and so supports the *lower* value

Jon Elsey, Univ of Reading



Modern (global and annual averaged) Earth energy budget



Stephens et al. (2012), Nature Geoscience 10.1038/NGEO1580

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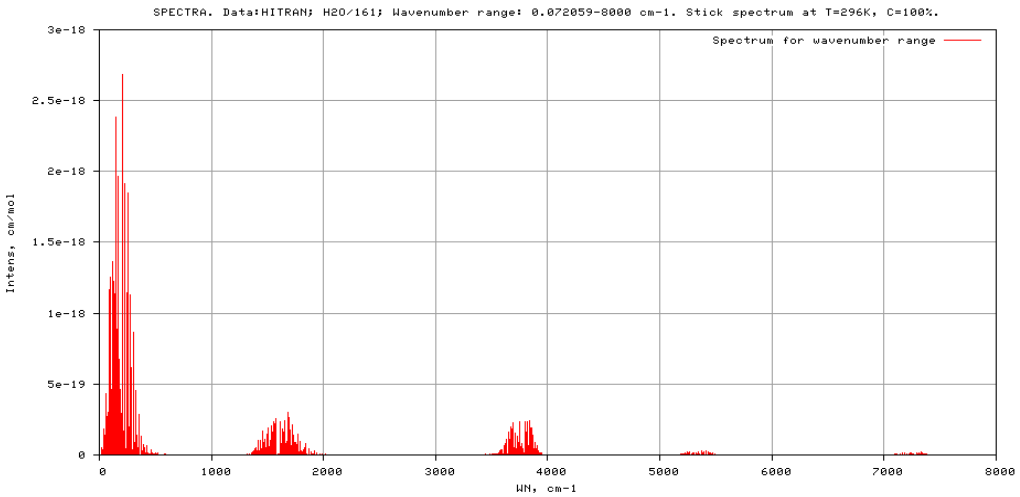
Between the water bands … the water vapour continuum



- Leading importance in the 10 micron mid-infrared window, but also important between the other water vapour bands
- No settled scientific cause – not today's subject
- But prior to 2000, there were almost no measurements of the continuum in the near-infrared windows. Today there are a few, but those that do exist do not agree. Most models use CKD/MT-CKD continuum, but there are few observational constraints in near-IR

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Journal of Molecular Spectroscopy 327 (2016) 193–208

The water vapour continuum in near-infrared windows – Current understanding and prospects for its inclusion in spectroscopic databases

Keith P. Shine [a,*], Alain Campargue [b,c], Didier Mondelain [b,c], Robert A. McPheat [d], Igor V. Ptashnik [e], Damien Weidmann [d]

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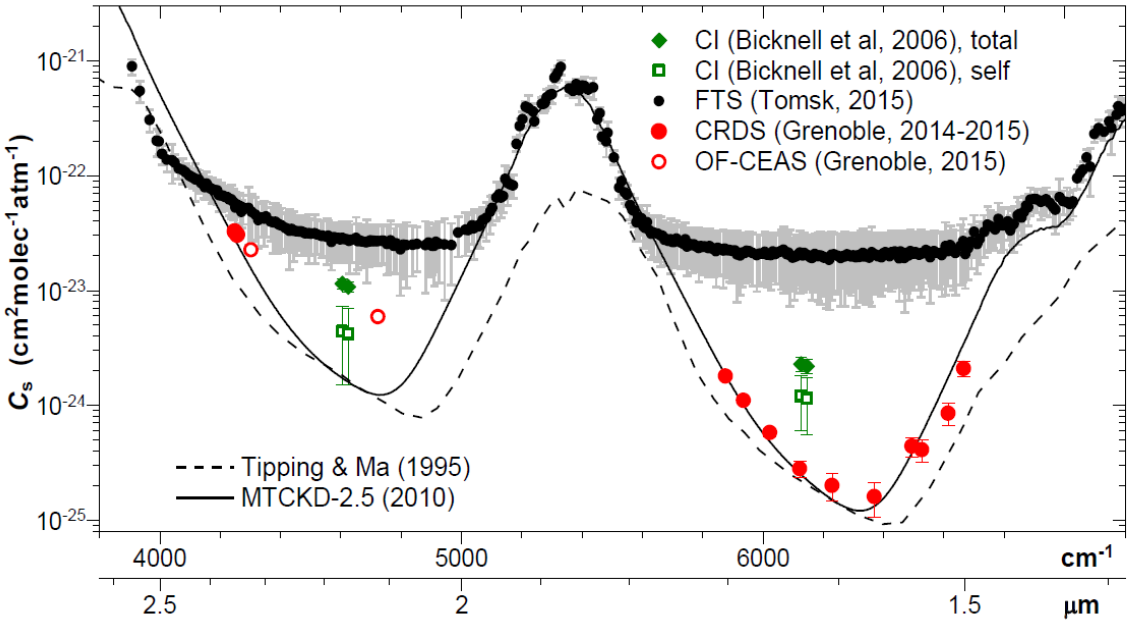
[b] Univ. Grenoble Alpes, LIPhy, F-38000 Grenoble, France
[c] CNRS, LIPhy, F-38000 Grenoble, France
[d] Space Science and Technology Department, Rutherford Appleton Laboratory, Chilton, Didcot, Oxon OX11 0QX, UK
[e] Spectroscopy Division, Zuev Institute of Atmospheric Optics SB RAS, 1 Akademichesky Av., Tomsk 634055, Russia



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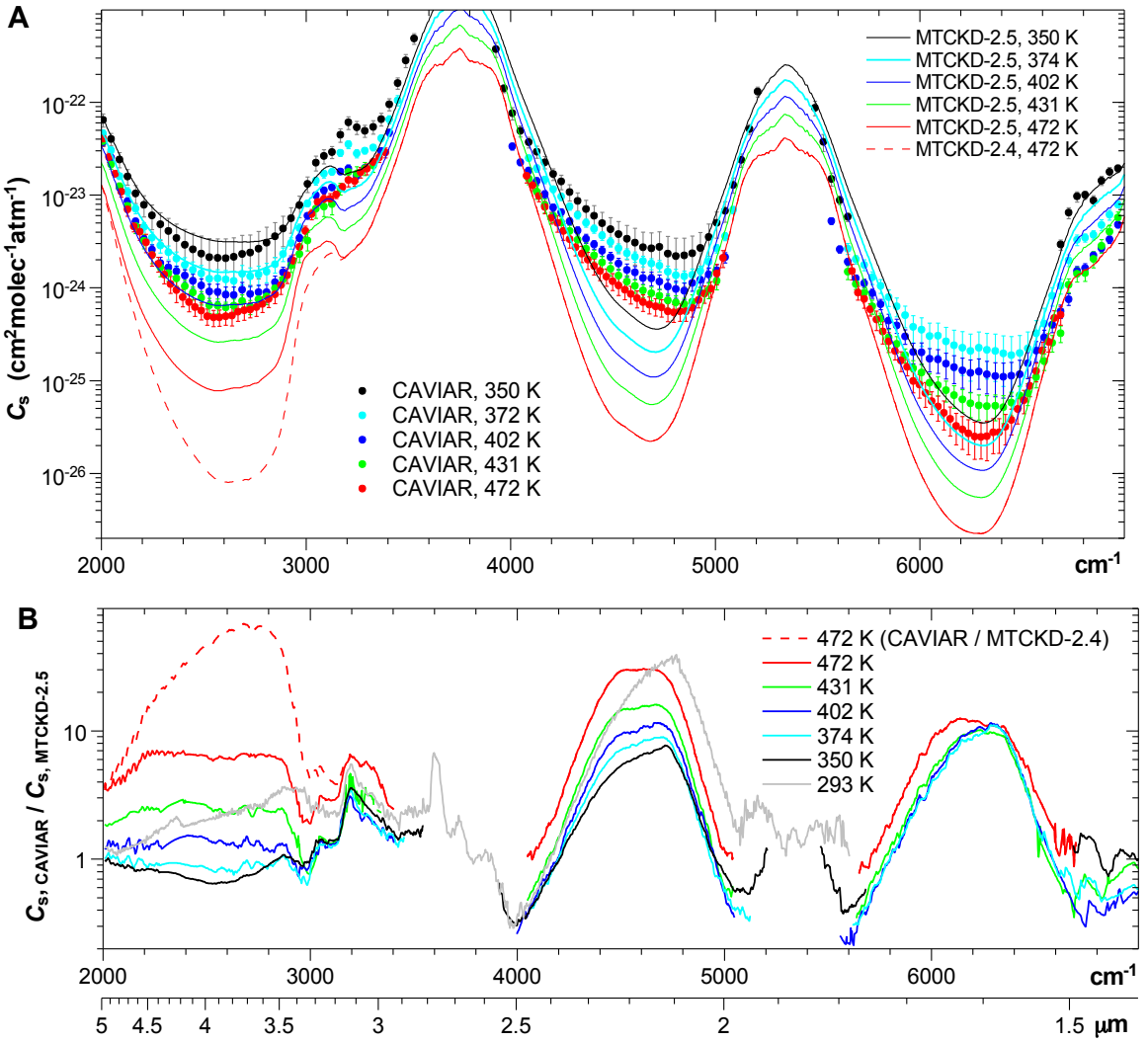
CAVIAR project (2006-2011) – indicates that widely-used continuum models are too weak. But most lab observations are necessarily at high temperature



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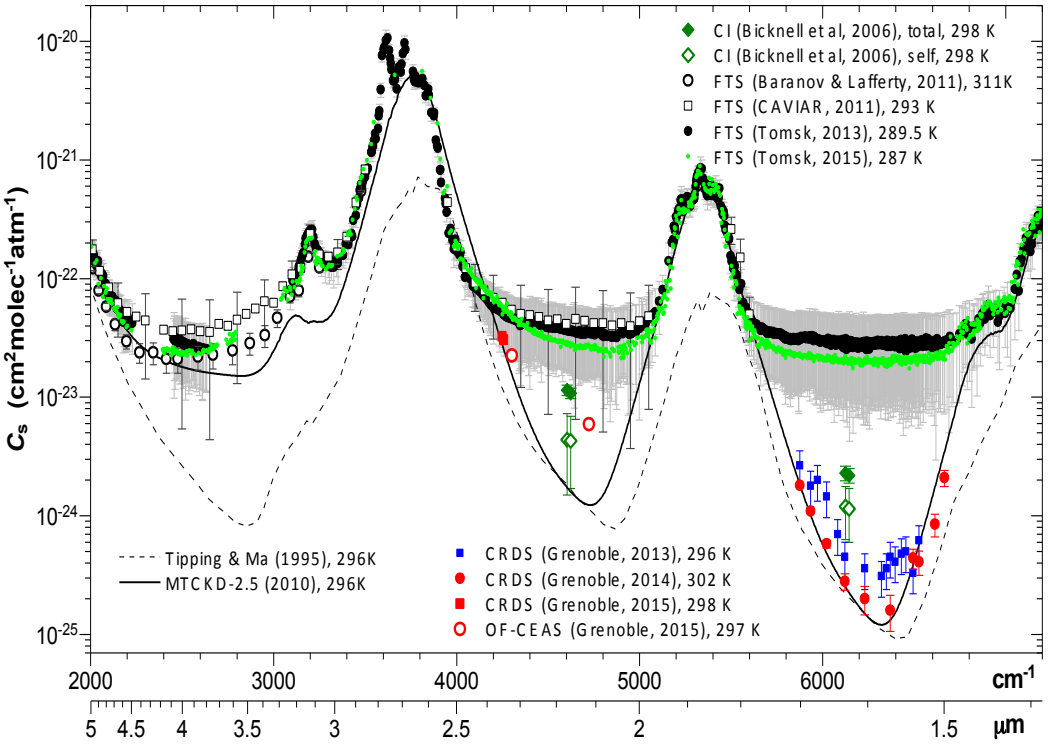
Few measurements near room temperature – main ones are from 3 groups: CAVIAR, Tomsk and Grenoble – and the degree of agreement can be very poor ... especially in the core of the 1.6 μm window



CAVIAR/Tomsk – uses Fourier Transform Spectrometry with large gas cells – large uncertainties at room temperature, but better at elevated temperatures

CRDS – Cavity Ringdown Spectroscopy with small gas cells. Inherently more precise. Limited wavenumbers

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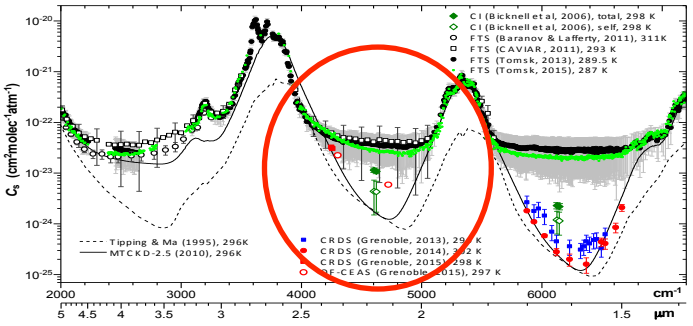
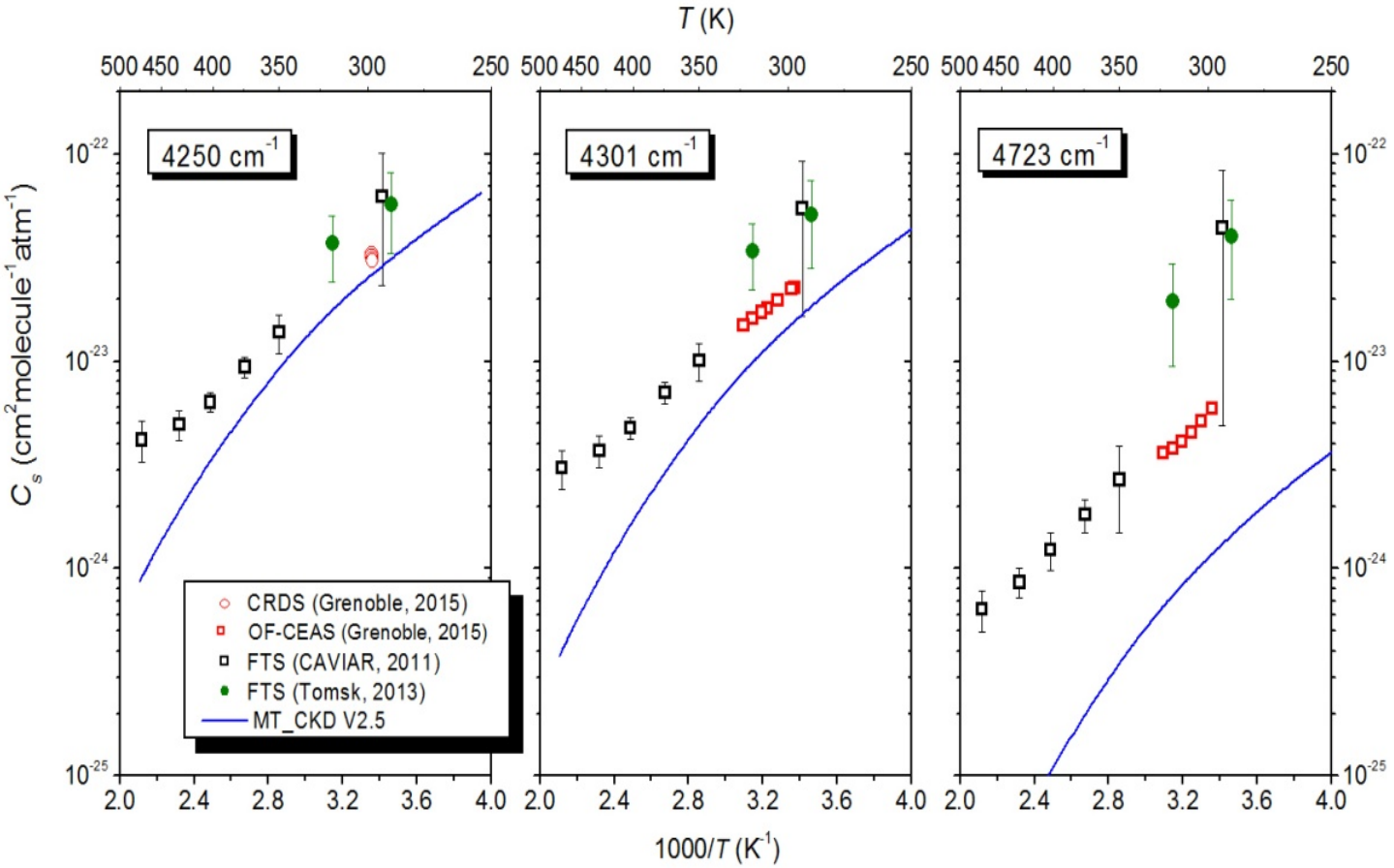


Temperature dependence is a *useful* diagnostic of consistency of measurements. In 2.1 μm window, high-T CAVIAR FTS data appears consistent with the Grenoble CRDS measurements



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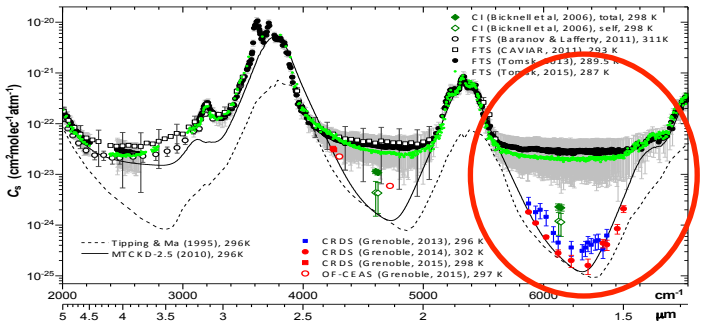
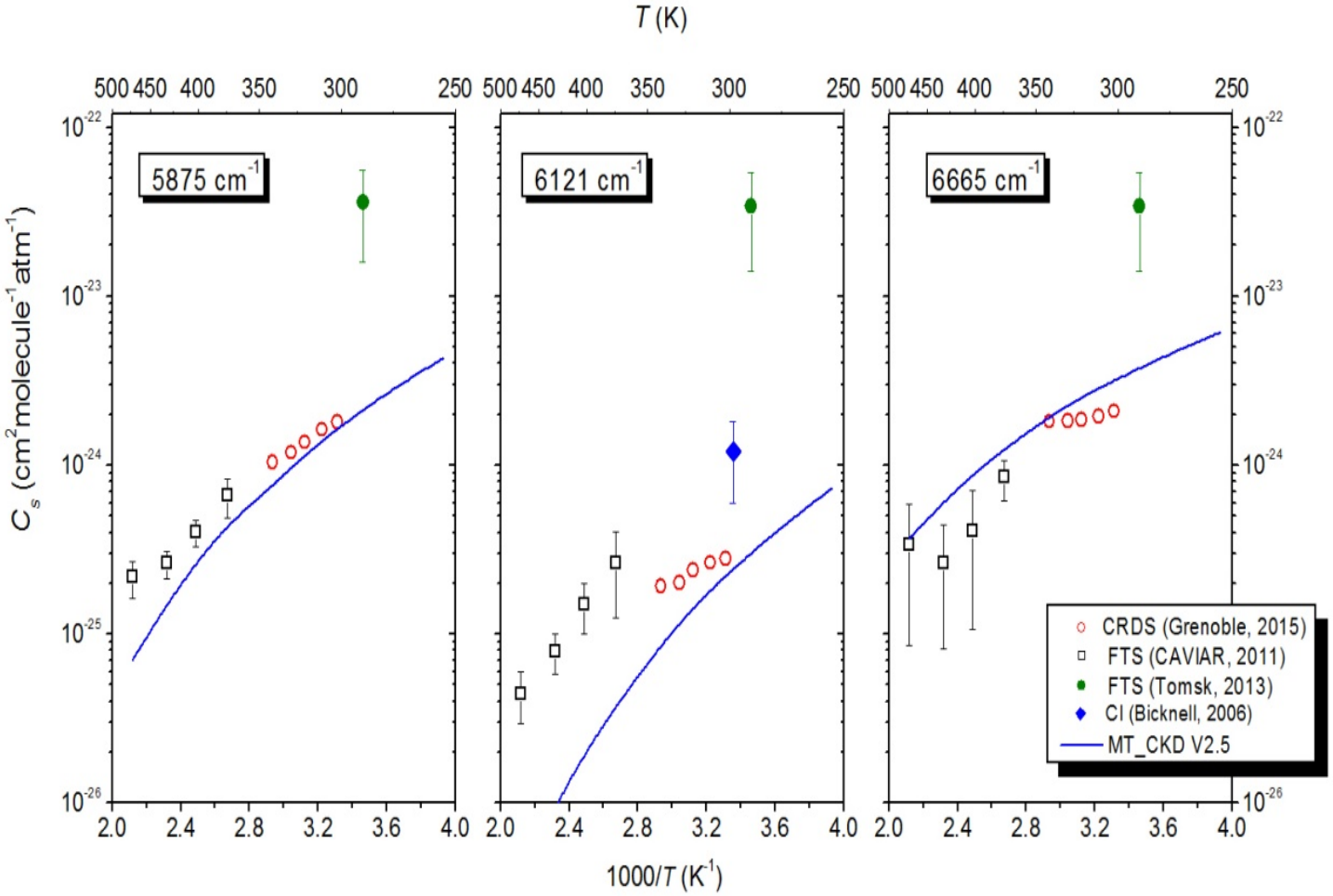


In the 1.6 μm window, high-T CAVIAR data appears much less consistent with CRDS, especially in the centre of the window. Why are 1.6 and 2.1 μm windows so different?



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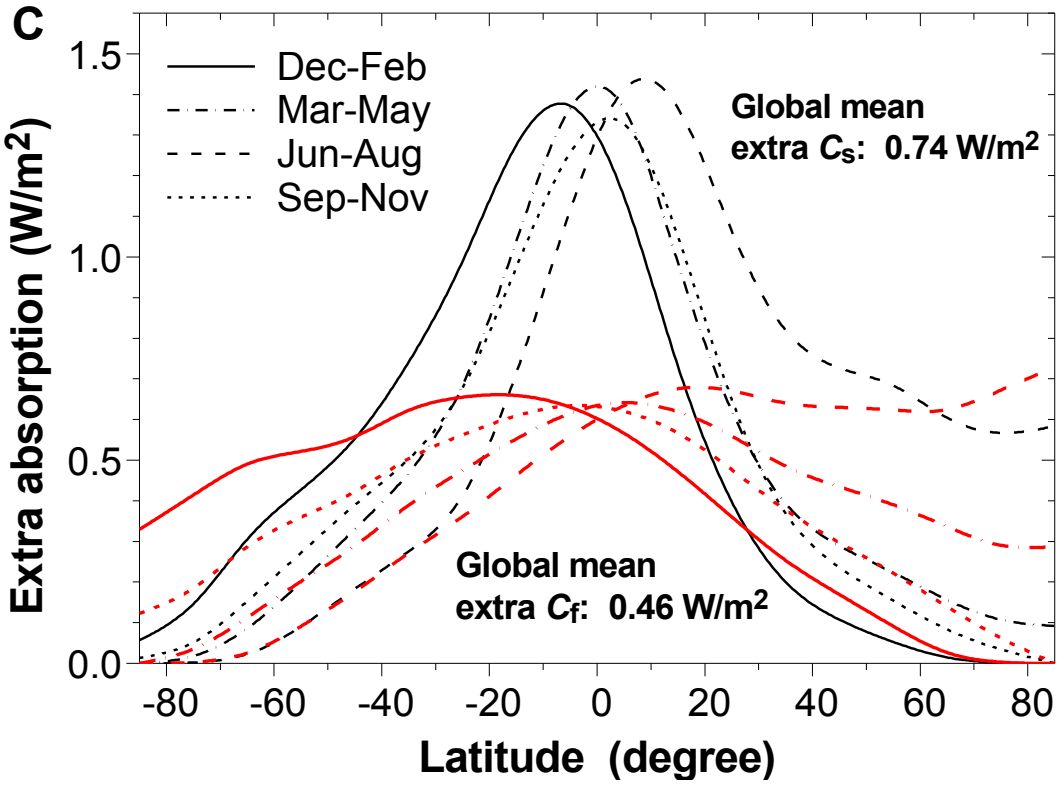
Global impact of new continuum for clear skies



Using the CAVIAR continuum increases the global-mean clear-sky atmospheric shortwave absorption by 2% compared to MT-CKD

But could be more or could be less, if different lab measurements used

In a warming world, this absorption increases by 12% more using CAVIAR continuum than MT-CKD

Ptashnik et al. (Phil Trans Roy Soc, 2012)

Rädel et al. (QJRMS, 2015)

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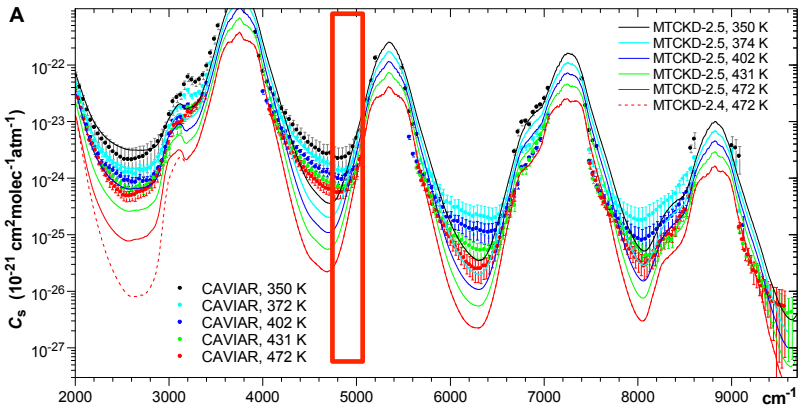
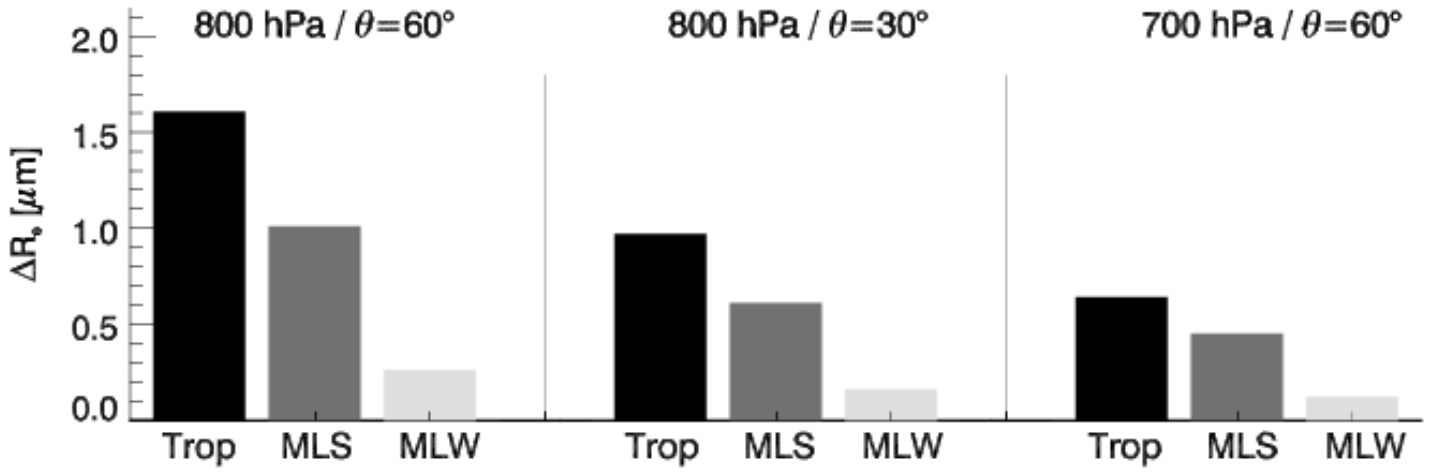
Impact on remote sensing of cloud properties

Satellite retrievals of cloud droplet radius (and much else) use 4900 cm^{-1} window (amongst others)



If CAVIAR continuum is used, it could systematically reduce the retrieved droplet radius by typically about 1 μm (in 10 μm). Depends on cloud height and location



Shine et al., Surveys in Geophys, 2012

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The water vapour continuum: some conclusions

• Significant differences in the observed continuum. Too few measurements and too little overlap in measurement conditions. *Could* be important for ERB and remote sensing

• Where next? New technology (e.g. super-continuum light sources), different cell geometries, “tight” intercomparisons, more measurements from different labs, and need to constrain using atmospheric observations (Jon Elsey’s PhD)

Thank you!

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